Improving Energy Consumption by Using Cluster Based Routing Algorithm in Wireless Sensor Networks

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ABSTRACT

Multi-path is favorite alternative for sensor networks, as it provides an easy mechanism to distribute traffic, as well as considerate fault tolerance. In this paper, a new clustering based multi path routing protocol namely ECRR (Energy efficient Cluster based Routing algorithm for improving Reliability) is proposed, which is a new routing algorithm and guarantees the achievement to required QoS of wireless sensor networks and can reduces the energy consumption. Proposed protocol has better performance in comparison the existing ones.

KEYWORDS: Energy consumption, multi-path, wireless sensor network, quality of service.

1. INTRODUCTION

With the specific consideration of the unique properties of sensor networks such limited power, stringent bandwidth, dynamic topology (due to nodes failures or even physical mobility), high network density and large scale deployments have caused many challenges in the design and management of sensor networks. These challenges have demanded energy awareness and robust protocol designs at all layers of the networking protocol stack [1]. Efficient utilization of sensor's energy resources and maximizing the network lifetime were and still are the main design considerations for the most proposed protocols and algorithms for sensor networks and have dominated most of the research in this area. The concepts of latency, throughput and packet loss have not yet gained a great focus from the research community. However, depending on the type of application, the generated sensory data normally have different attributes, where it may contain delay sensitive and reliability demanding data. For example, the data generated by a sensor network that monitors the temperature in a normal weather monitoring station are not required to be received by the sink node within certain time limits. On the other hand, for a sensor network that used for fire detection in a forest, any sensed data that carries an indication of a fire should be reported to the processing center within certain time limits. Furthermore, the introduction of multimedia sensor networks along with the increasing interest in real time applications have made strict constraints on both throughput and delay in order to report the time-critical data to the sink within certain time limits and bandwidth requirements without any loss. These performance metrics (i.e. delay, energy consumption and bandwidth) are usually referred to as Quality of Service (QoS) requirements [2]. Therefore, enabling many applications in sensor networks requires energy and QoS awareness in different layers of the protocol stack in order to have efficient utilization of the network resources and effective access to sensors readings. Thus QoS routing is an important topic in sensor networks research, and it has been under the focus of the research community of WSNs. Refer to [2] and [3] for surveys on QoS based routing protocol in WSNs.

Many routing mechanisms specifically designed for WSNs have been proposed [4], [5]. In these works, the unique properties of the WSNs have been taken into account. These routing techniques can be classified according to the protocol operation into negotiation based, query based, QoS based, and multi-path based. The negotiation based protocols have the objective to eliminate the redundant data by include high level data descriptors in the message exchange. In query based protocols, the sink node initiates the communication by broadcasting a query for data over the network. The QoS based protocols allow sensor nodes to make a tradeoff between the energy consumption and some QoS metrics before delivering the data to the sink node [6]. Finally, multi-path routing protocols use multiple paths rather than a single path in order to improve the network performance in terms of reliability and robustness. Multi-path routing establishes multiple paths between the source-destination pair. Multi-path routing protocols have been discussed in the literature for several years now [7].

2. RELATED WORK

Some QoS oriented routing works are surveyed in [2] and [3]. One of the early proposed routing protocols that provide some QoS is the Sequential Assignment Routing (SAR) protocol [8]. SAR protocol is a multi-path routing protocol that makes routing decisions based on three factors: energy resources, QoS on each path, and packet's priority level. Multiple paths are created by building a tree rooted at the source to the destination. During construction of paths those nodes which have low QoS and low residual energy are avoided. Upon the construction of the tree, most of the nodes will belong to multiple paths. To transmit data to sink, SAR computes a weighted QoS metric as a product of the additive QoS metric and a weighted coefficient associated with the priority level of the packet to select a path. Employing multiple paths increases fault tolerance, but SAR protocol suffers from the overhead of maintaining routing tables and QoS metrics at each sensor node.

K. Akkaya and M. Younis in [9] proposed a cluster based QoS aware routing protocol that employs a queuing model to handle both real-time and non real time traffic. The protocol only considers the end-to-end delay. The protocol associates a cost function with each link and uses the K-least-cost path algorithm to find a set of the best candidate routes. Each of the routes is checked against the end-to-end constraints and the route that satisfies the constraints is chosen to send the data to the sink. All nodes initially are assigned the same bandwidth ratio which makes constraints on other nodes which require higher bandwidth ratio. Furthermore, the transmission delay is not considered in the estimation of the end-to-end delay, which sometimes results in selecting routes that do not meet the required end-to-end delay. However, the problem of bandwidth assignment is solved in [10] by assigning a different bandwidth ratio for each type of traffic for each node.

SPEED [11] is another QoS based routing protocol that provides soft real-time end-to-end guarantees. Each sensor node maintains information about its neighbors and exploits geographic forwarding to find the paths. To ensure packet delivery within the required time limits, SPEED enables the application to compute the end-to-end delay by dividing the distance to the sink by the speed of packet delivery before making any admission decision. Furthermore, SPEED can provide congestion avoidance when the network is congested.

Felemban et al. [12] propose Multi-path and Multi-Speed Routing Protocol (MMSPEED) for probabilistic QoS guarantee in WSNs. Multiple QoS levels are provided in the timeliness domain by using different delivery speeds, while various requirements are supported by probabilistic multipath forwarding in the reliability domain.

Recently, X. Huang and Y. Fang have proposed multi constrained QoS multi-path routing (MCMP) protocol [13] that uses braided routes to deliver packets to the sink node according to certain QoS requirements expressed in terms of reliability and delay. The problem of the end-to-end delay is formulated as an optimization problem, and then an algorithm based on linear integer programming is applied to solve the problem. The protocol objective is to utilize the multiple paths to augment network performance with moderate energy cost. However, the protocol always routes the information over the path that includes minimum number of hops to satisfy the required QoS, which leads in some cases to more energy consumption. Authors in [14], have proposed the Energy constrained multi-path routing (ECMP) that extends the MCMP protocol by formulating the QoS routing problem as an energy optimization problem constrained by reliability, playback delay, and geo-spatial path selection constraints. The ECMP protocol trades between minimum number of hops and minimum energy by selecting the path that satisfies the QoS requirements and minimizes energy consumption. RFTM [15] is a multi objective routing protocol that meets diverse application requirements by considering the changing conditions of the network. The protocol takes into account both reliability demand and link quality to determine the number of desired multiple disjoint paths between the sink and source nodes. Authors in [16] have proposed the Sleeping Multipath Routing, which selects the minimum number of disjoint paths to achieve a given reliability requirement and puts the rest of the network to sleep.

Many protocols have suggested in previous papers for clustering in WSNs. HEED [17] is a well-known clustering based routing algorithms in WSN. Cluster head selection algorithm is based on a relationship between remaining energy and reference energy in HEED. Meeting QoS requirements in WSNs introduces certain overhead into routing protocols in terms of energy consumption, intensive computations, and significantly large storage. This overhead is unavoidable for those applications that need certain delay and bandwidth requirements.

3. PROPOSED PROTOCOL

We explain the assumptions and energy model and then describe the main parts of the proposed protocol.

3.1 Assumptions

- All nodes are uniformly distributed in desired environment.
- Each node has a unique ID in network.
- The initial energy is the same for all nodes.
- Nodes are aware of the location (by positioning schemes such as [18]).
- Nodes are able to control their energy consumption.
- Nodes are aware from their remaining energy and also from the remaining energy of other nodes which are in their transmission radio range.
- Each pair of nodes can calculate their link quality.

3.2 ENERGY CONSUMPTON MODEL

In ECRR, energy model is obtained from [21] that use both of the open space (energy dissipation d^2) and multi path (energy dissipation d^4) channels by taking amount the distance between the transmitter and receiver. So energy consumption for transmitting a packet of l bits in distance d is given by (1).

$$E_{Tx}(l,d)=\begin{cases} lE_{elec}+l\varepsilon_{fs}d^{2} & , \mathrm{d} \le \mathrm{d}_0 \\ lE_{elec}+l\varepsilon_{mp}d^{4} & , \mathrm{d} > \mathrm{d}_0 \end{cases} \quad (1)$$

In here d_0 is the distance threshold value which is obtained by (2), E_{elec} is required energy for activating the electronic circuits. ε_{fs} and ε_{mp} are required energy for amplification of transmitted signals to transmit a one bit in open space and multi path models, respectively.

$$d_0=\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (2)$$

Energy consumption to receive a packet of l bits is calculated by (3).

$$E_{Rx}(l)=lE_{elec} \quad (3)$$

3.3 ECRR

ECRR has different phases like the other routing protocols for cluster formation and data transmitting that are Information collecting from neighbor nodes, link cost and link merit calculation and forwarder node selection.

The cluster head announcement phase which is cluster head selection phase is almost like a cluster head selection algorithm in HEED but the difference is that in the beginning, all nodes calculates the probability of cluster head selection by (4) and then follows from the operations in the HEED.

$$C\_V_{CH}=\alpha(\frac{E_r}{E_i})+(1-\alpha)(\frac{D_m-D_{CH,S}}{D_m}) \quad (4)$$

Where, α and 1-α are influence coefficients of energy and distances, respectively. E_r is remaining energy of sensor node and E_i is initial energy of sensor. D_m and $D_{CH,S}$ are the longest distance to the base station (same as network diameter) and the distance between desired node and base station, respectively.

In cluster formation phase, all ordinary nodes calculate the merit value of the cluster heads that are on their radio transmission range by (5). Then they join to the cluster head that its merit value is greater than the others.

$$M\_V_{CH}=\alpha(E_r)+(1-\alpha)(LQ_{N,CH}) \quad (5)$$

Where, α and 1-α are influence coefficients of energy and link quality, respectively. $LQ_{N,CH}$ is the value of link quality between ordinary node and the cluster head.

Data transmitting phase contains three steps that is explained in the next separately.

- **Link Merit and Link Cost**

The merit and cost of the link are used by the node to select the other node at the next hop as a forwarder during the path discovery phase.

Source node calculates the merit and cost of the links between itself and each its neighbors by (6) and (7), respectively.

$$L\_M_{ij}=\alpha(PSPS)_j+(1-\alpha)(LQ_{ij}) \quad j \in N_i \quad (6)$$

$$L\_C_{ij} = (E_{cost})_i \quad (7)$$

Where, node i is a source node and node j is the node at the next hop. Let N_i be a set of neighbors of node i. $PSPS_j$ is the probability of successfully packet sending of node j. LQ_{ij} is the value of link quality between i and j. α is the influence coefficient of this parameter. E_{cost} is the amount of required energy for sending a packet from i to j and is calculated by (8) [22].

$$E_{cost} = \frac{[(D_{i,j})^2]^{\theta}}{[(E_r)_i]^{\omega}} \quad (8)$$

Where, $D_{i,j}$ is the distance between I and j. θ and ω are influence coefficients of each used parameters.

Node i select a node from set of its neighborhoods that has maximum link merit and also has minimum link cost.

- **Path Discovery**

In multi-path routing, node-disjoint paths are usually preferred because they utilize the most available network resources, and hence are the most fault-tolerant [19].

In first phase of path discovery procedure, each cluster heads collects the needed information about its neighbors by beacon exchange between them and then updates itself neighboring table. After this phase, each cluster head has enough information to compute the link merit for its neighboring nodes.

Then sink broadcasts the RREQ (route request) message to all neighboring cluster heads to path discovery. Fig. 1 illustrates the RREQ message structure.

Table 1. RREQ message structure

Source ID	Path ID	TM_P	TC_P

Here, TM is total merit of link and TC is total cost of link.

Then the cluster head at the next hop which receives RREQ message selects the its preferred cluster head at the next hop using the link merit function locally, and sends out a RREQ message to its most preferred next hop. This operation continues until source and TM_p and TC_p are updated at each hop. To avoid having the paths with shared node and to create disjoint paths, we limit each node to accept only one RREQ message with the same source ID.

- **Path Selection**

After the execution of paths discovery phase and the paths have been constructed, we need to select a set of paths from the N available paths to transfer the traffic from the source to the destination with a desired bound of data delivery given by α. To find the number of required paths, we assume that each path is associated with some rate pi (i=1, 2 … N) that corresponds to the probability of successfully delivering a message to the destination. Following the work done in [20], the number of required paths is calculated by (9).

$$k = x_a \sqrt{\sum_{i=1}^{N} p_i (1 - p_i)} + \sum_{i=1}^{N} p_i. \quad (9)$$

In here, x_a is the corresponding bound from the standard normal distribution for different levels of α. Table I lists some values for x_α.

Table 2. Some values for the different bounds[20]

α	95%	90%	85%	80%	50%
x_a	-1.65	-1.28	-1.03	-0.85	0

4. SIMULATION AND PERFORMANCE EVOLUTION

We have used the GCC to implement and simulate ECRR and compare it with the EQSR. Simulation parameters are presented in Table I and obtained results are shown below. The radio model used in the simulation was a duplex transceiver. The network stack of each node consists of IEEE 802.11 MAC layer with 30 meter transmission range. Data rate is 200 kbps, transmission power is 2 mw and RREQ message length is 10 bytes. The values of θ and ω are 1 and 50, respectively. It is assumed that the values of other influence coefficients are equal with each other.

4.1 AVERAGE END-TO-END DELAY

The average end-to-end delay is the time required to transfer data successfully from source node to the destination node. Fig. 2 shows the average end to end delay for ECRR and EQSR. As it can be seen, proposed protocol has performance better than EQSR in average end to end delay.

4.2 AVERAGE ENERGY CONSUMPTION

The average energy consumption is the average of the energy consumed by the nodes participating in message transfer from source node to the destination node. Fig. 3 shows the results for energy consumption in ECRR and EQSR. As it can be seen, the proposed protocol is more energy efficient than EQSR.

Table 3. Simulation Parameters

Parameters	Value
Network area	400 meters × 400
Base station	(0, 0) m
Number of	100
Initial energy	2J
E_{elec}	50 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
d_0	87 m
E_{DA}	5 nJ/bit/signal
Beacon packet	30 bytes
Data packet size	512 bytes

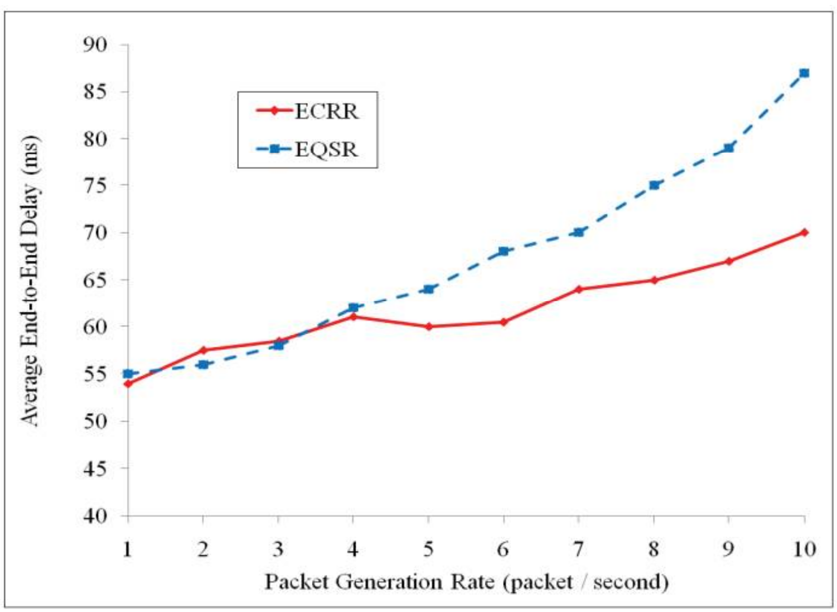

Fig.1. Average end to end delay

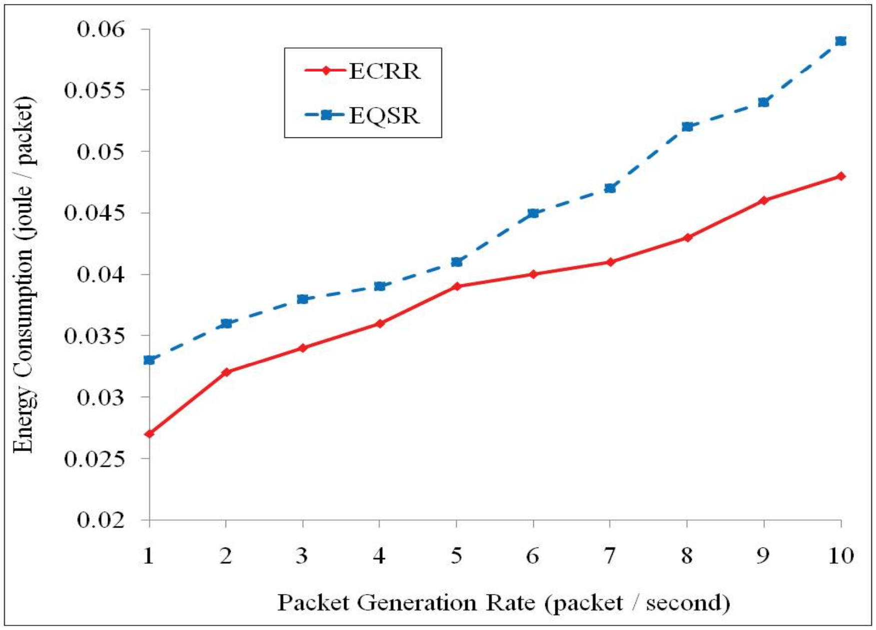

Fig.2. Average energy consumption

4.3 AVERAGE PACKET DELIVERY RATIO

The average delivery ratio is the number of packets generated by the source to the number of packets received by the destination node. Fig. 4 shows the average delivery ratio. Obviously, ECRR outperforms the EQSR.

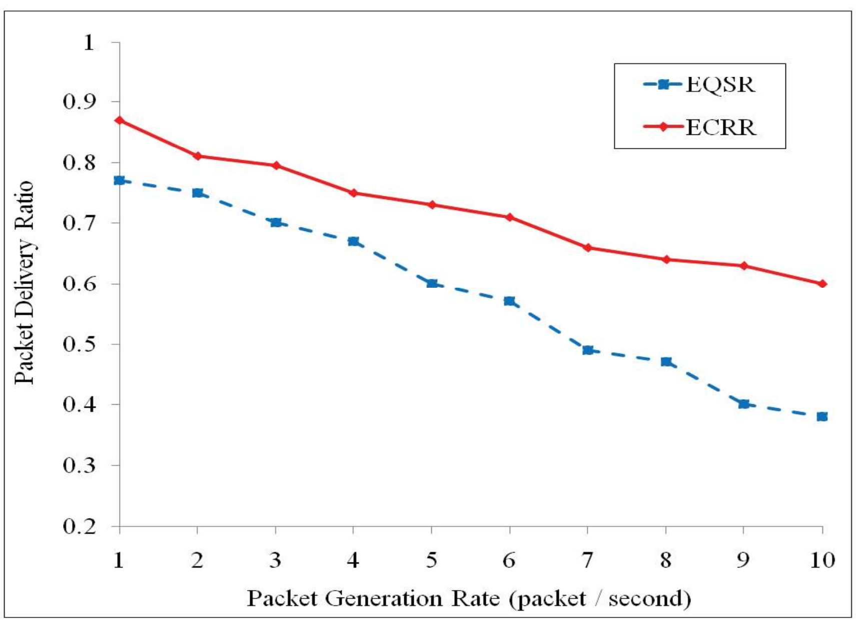

Fig.3. Packets delivery ratio

5. CONCLUSION

In this paper, a new clustering based multi path routing protocol namely ECRR is proposed, which guarantees achieve to required QoS of wireless sensor networks and can reduces the energy consumption. ECRR considers the link cost function with the link merit function in selecting the forwarder node in routing mechanism. Simulation Result shows that the performance of ECRR is efficient than EQSR.

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